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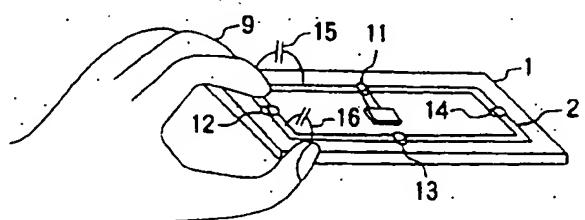
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## (54) Receiving apparatus and transmitting apparatus in a thin form

(57) A transmitter or receiver is designed to prevent the change in the resonance frequency of a loop antenna 2 caused by stray capacitances 15 and 16, produced when the loop antenna is in close proximity to a human body 9, by means of shunting or absorbing the stray capacitances. A loop conductor 2 is formed in the shape of a polygon, circle, or an ellipse. Capacitors 11-14 are disposed on each side, or at each vertex, or at each point inscribed with the case structure so that the impedance between two vertices or two inscribed points between which the stray capacitance is coupled becomes zero at a specified resonance frequency. The shape of the loop and the position of the capacitances can be chosen in accordance with predefined likely points of stray capacitance coupling (figures 7-10). The loop conductor may also be formed on either side of a substrate so that a capacitance is created by large-area parts of the conductor disposed near the short sides of the substrate, thereby absorbing the stray capacitance which is most likely to occur near the short sides.

FIG. 4



15,16 : STRAY CAPACITANCE PRODUCED  
BETWEEN THE LOOP CONDUCTOR  
AND A HAND.

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FIG. 1

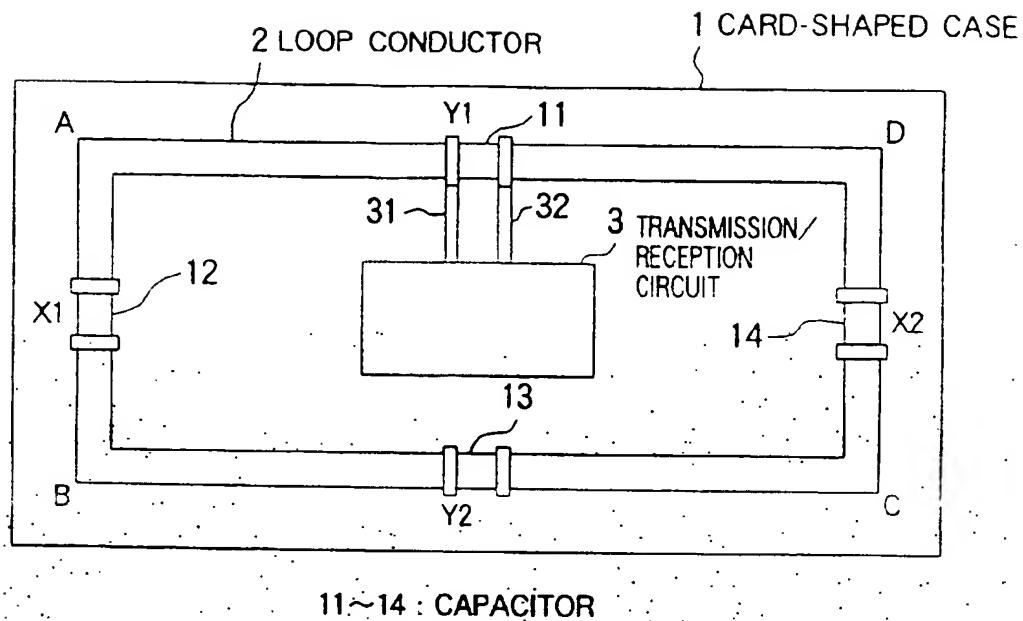
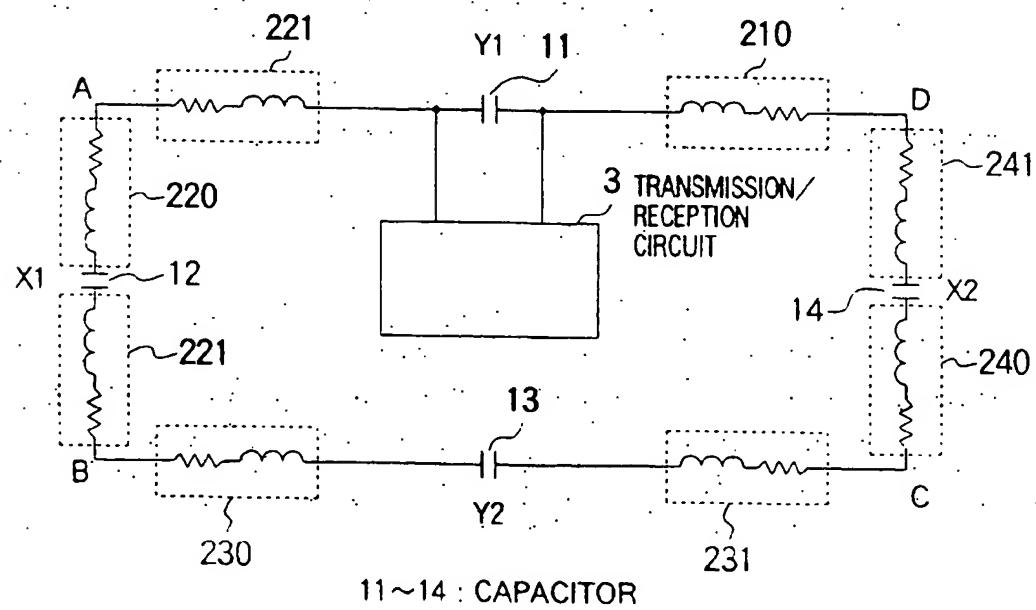


FIG. 2



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FIG. 3

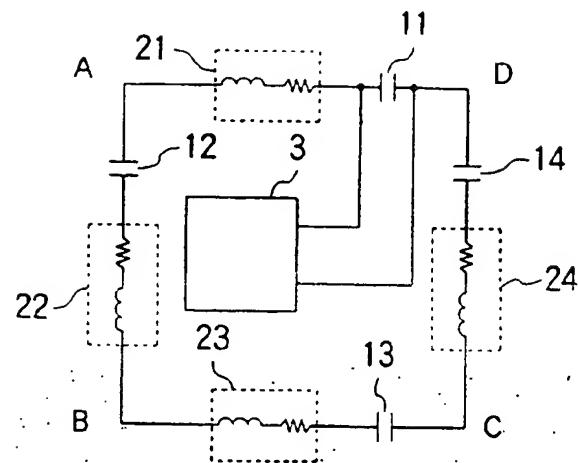
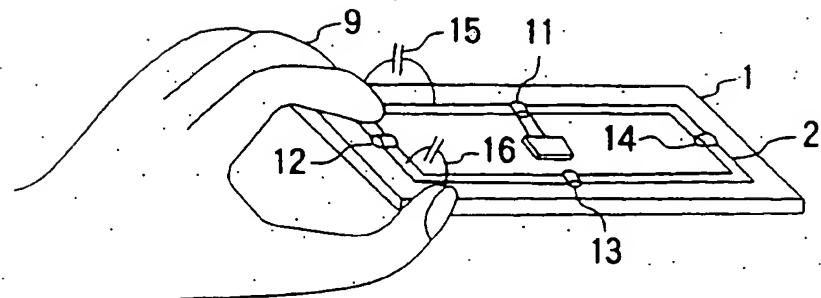


FIG. 4



15,16 : STRAY CAPACITANCE PRODUCED  
BETWEEN THE LOOP CONDUCTOR  
AND A HAND

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FIG. 5

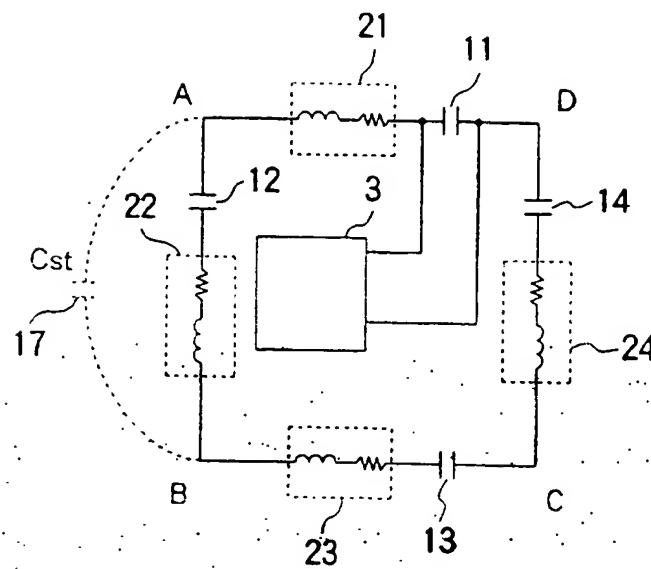
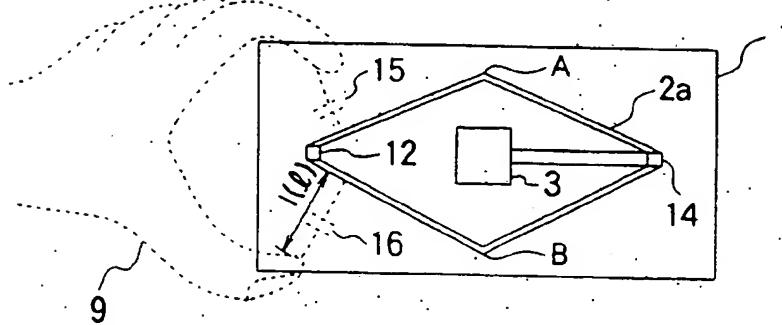


FIG. 6



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FIG. 7

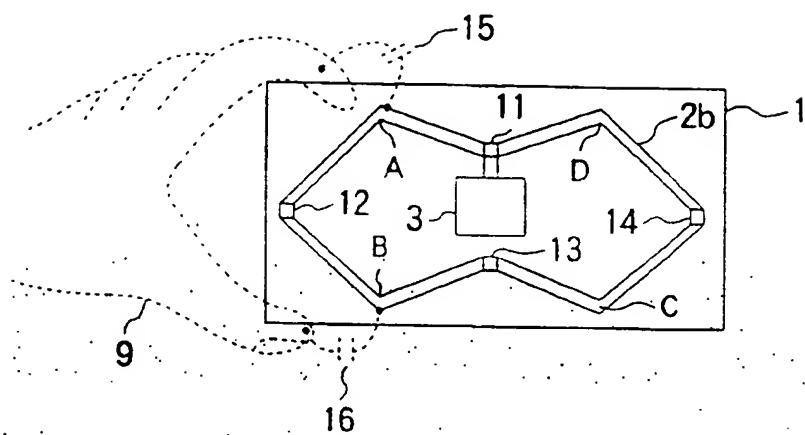
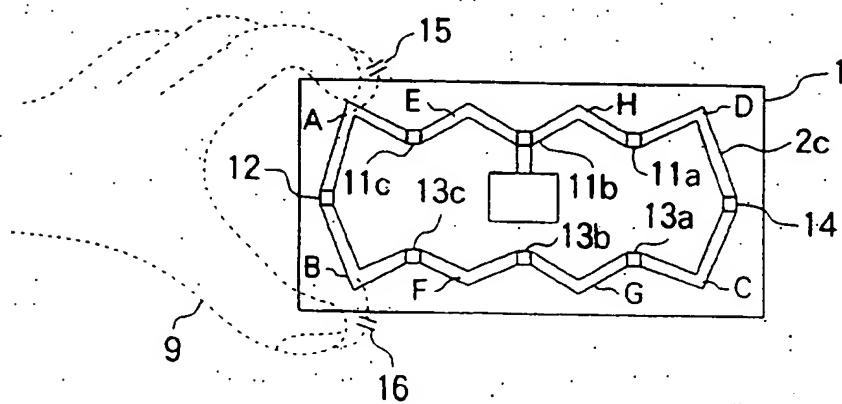
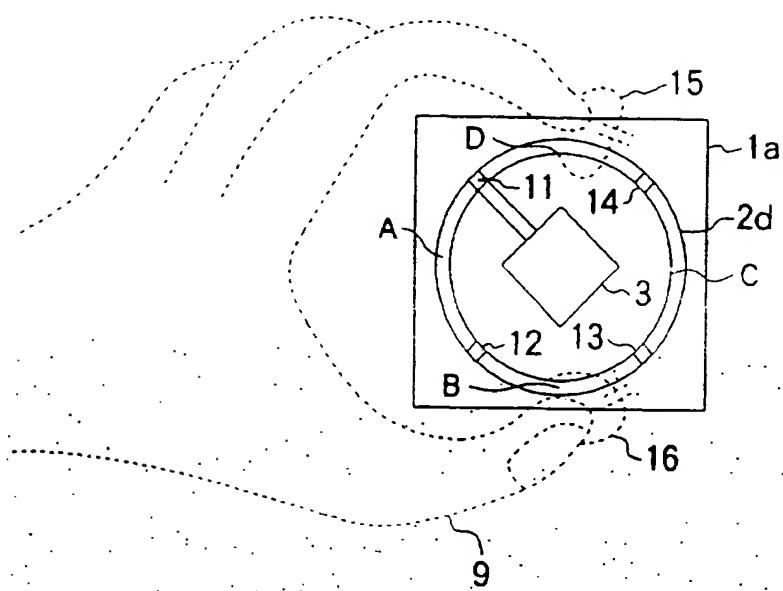


FIG. 8

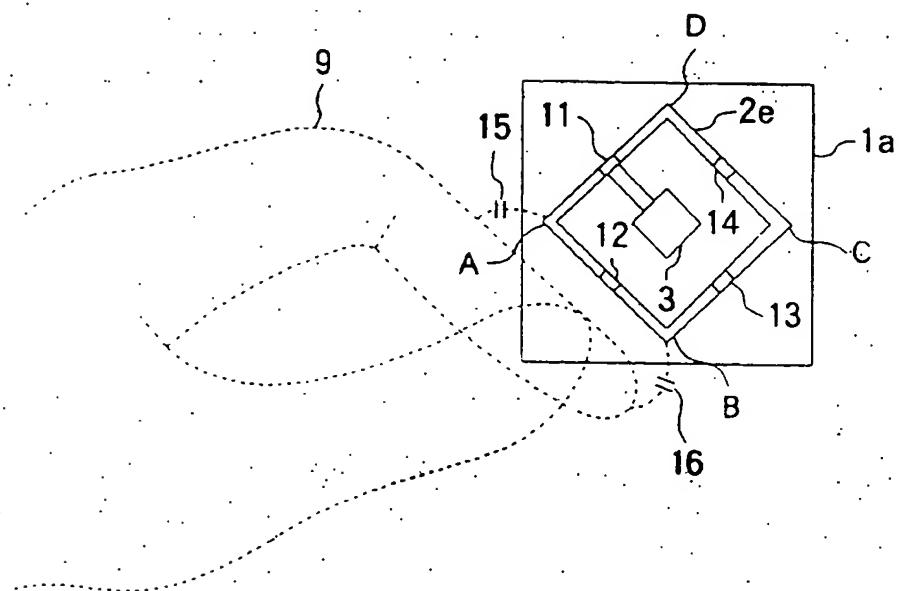


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**FIG. 9**



**FIG. 10**



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FIG. 11

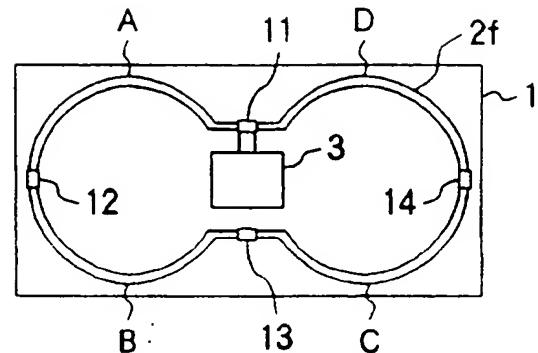
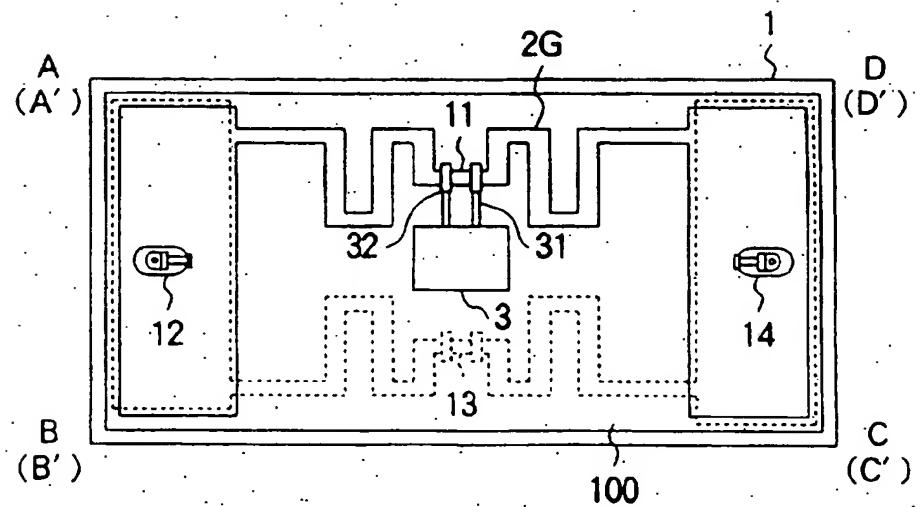


FIG. 12



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FIG. 13

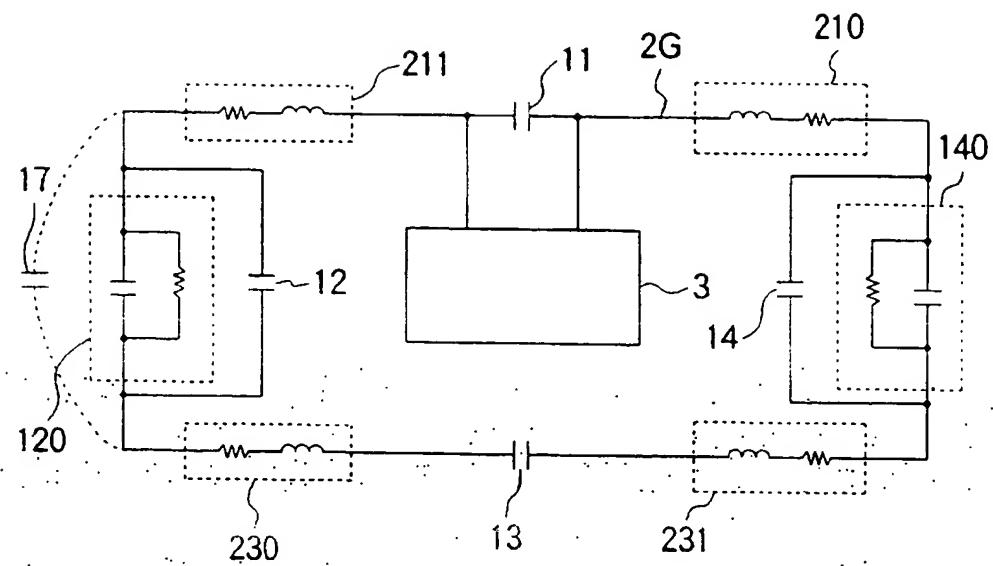
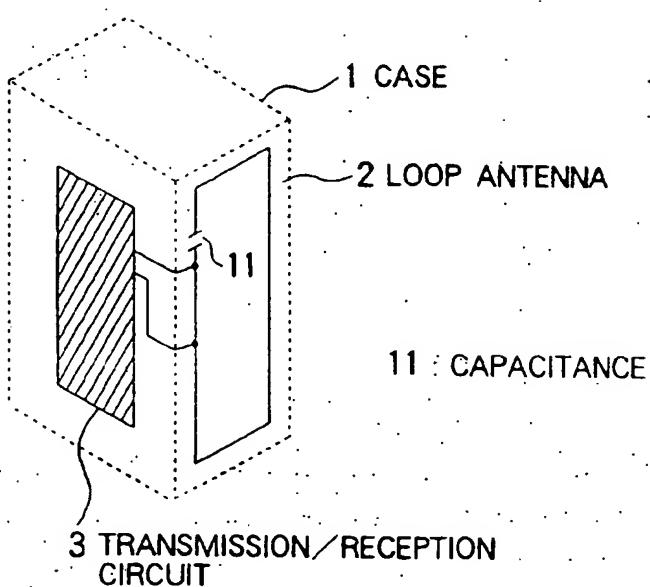


FIG. 14



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FIG. 15

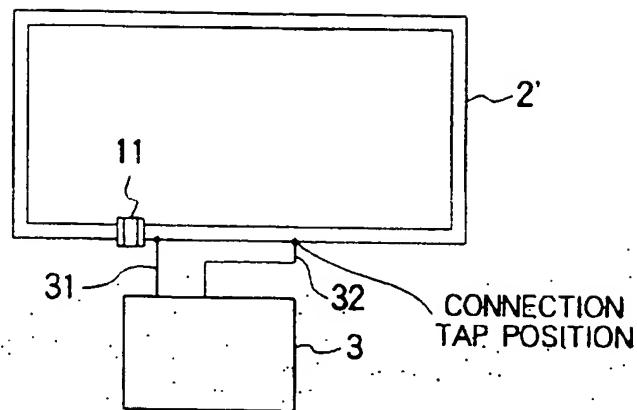
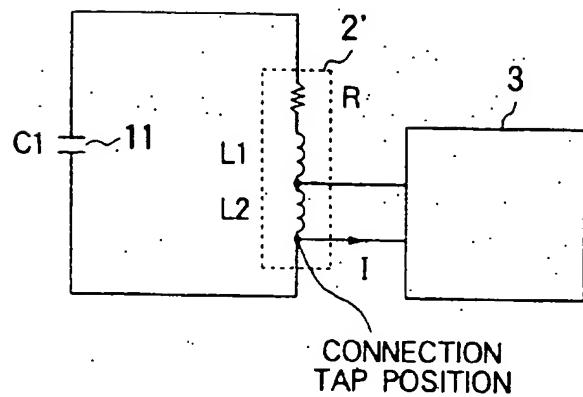


FIG. 16



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FIG. 17

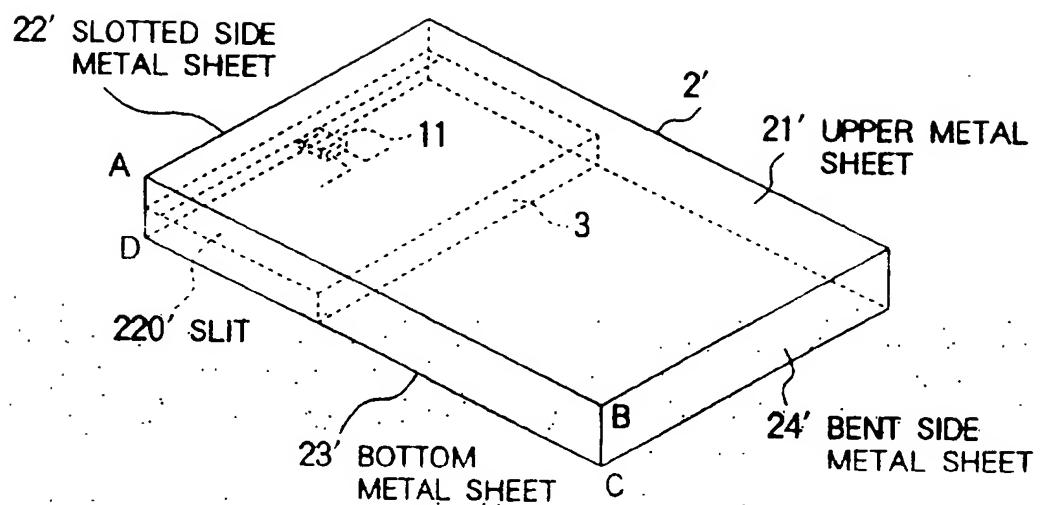
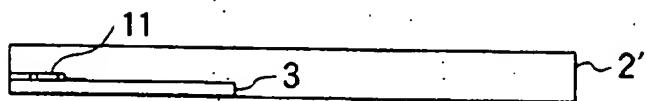


FIG. 18



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FIG. 19

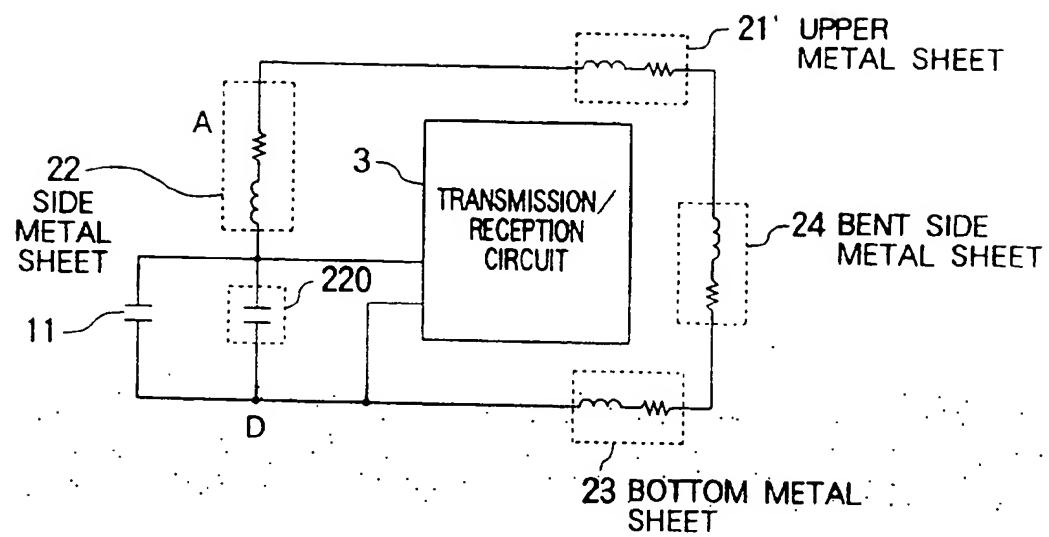


FIG. 20

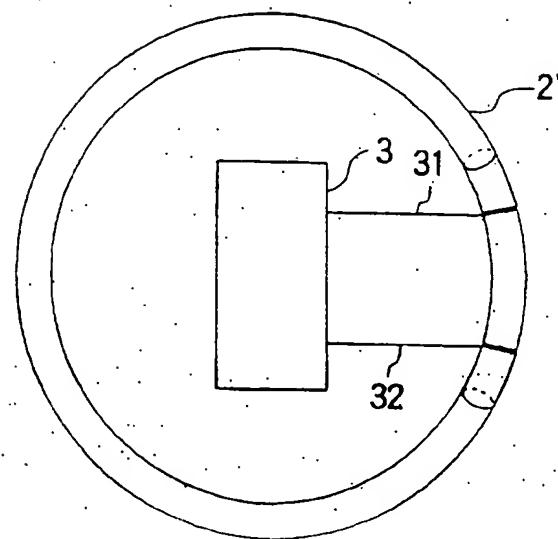
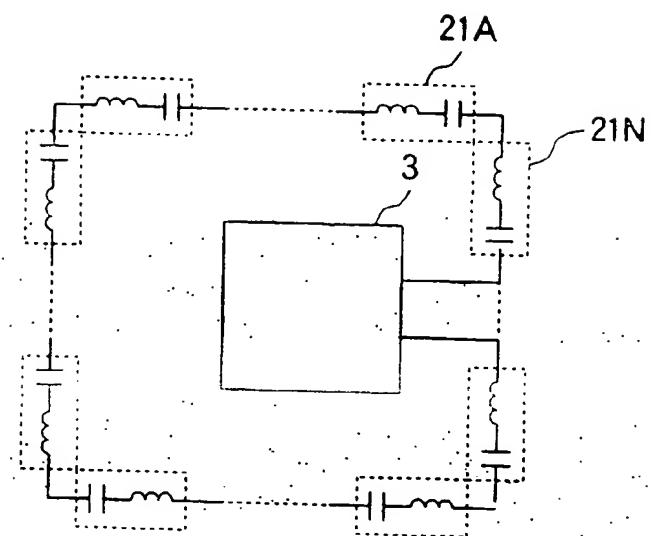


FIG. 21



## RECEIVING APPARATUS AND TRANSMITTING APPARATUS IN A THIN FORM

The present invention relates to a receiving apparatus in a thin form or a transmitting apparatus in a thin form.

In the accompanying drawings, Fig. 14 illustrates the appearance of a loop antenna for use in a pager, disclosed in HAM Journal, Oct., 1994, p. 50, wherein a similar antenna is also disclosed in the Transactions of the Institute of Electronics, Information, and Communications Engineers, Vol. 71-B, No. 11, November, p. 1208.

In Fig. 14, reference numeral 1 denotes a case; 2' a loop antenna disposed on a side of the case 1; 3 a transmission/reception circuit for transmitting and receiving radio waves via the loop antenna 2'; and 4 a capacitor inserted in series in the loop antenna 2'.

Fig. 15 is a plan view illustrating the loop antenna 2' for use in a pager shown in Fig. 14, developed on a plane. In Fig. 15, similar parts to those in Fig. 14 are designated by similar reference numerals. Reference numerals 31 and 32 denote the positions of connection taps at which lead wires extending from the transmission/reception circuit 3 are connected to the loop antenna 2'.

Fig. 16 illustrates an electric circuit equivalent to that shown in Fig. 15. In Fig. 16, similar parts to those in Fig. 15 are designated by similar reference numerals.

The operation of the loop antenna 2' will be described below with reference to the equivalent electric circuit shown in Fig. 16. The loop antenna 2' includes inductances  $L_1$  and  $L_2$ , and resistance  $R$  consisting of DC- and RF-loss resistance and

radiation resistance connected in series, wherein the values of these elements depend on the form of the loop antenna, the form of the conductor constituting the loop antenna, and the material thereof. An electric current  $I$  flows through the combined impedance of the impedance  $Z_2$  of the inductance  $L_2$ , and the input impedance  $Z_i$  of the transmission/reception circuit 3, wherein the above electric current  $I$  is determined by the voltage  $E_0$  induced by the received radio wave and the combined series impedance of the circuit of the loop antenna 2' as described by the following equation:

$$I = E_0 / [Z_1 + Z_2 // Z_i + Z_c + R] \quad (1)$$

where  $Z_1$  is the impedance of the inductance  $L_1$ , and  $Z_c$  is the impedance of the capacitor 11. In equation (1) and also elsewhere in this specification, symbol "://" is used to denote the operator of determining the overall impedance of a parallel connection of two impedances. That is, the overall impedance of a parallel connection of  $Z_a$  and  $Z_b$  is given as:

$$Z_a // Z_b = (Z_a \cdot Z_b) / (Z_a + Z_b)$$

The impedance  $Z_2 // Z_i$  of the parallel connection of the impedance  $Z_2$  of the inductance  $L_2$  and the input impedance  $Z_i$  of the transmission/reception circuit 3 can be converted into an equivalent representation in the form of a series connection of  $Z_2'$  and  $Z_i'$  according to the following equation:

$$Z_2 // Z_i = Z_2' + Z_i' \quad (2)$$

At the resonance frequency  $f_r$  of the loop antenna of the pager, the impedances  $Z_1$  and  $Z_2$  of the inductors  $L_1$  and  $L_2$ , and the impedance  $Z_c$  of the capacitor 11 become 0 as the whole, and thus equation 1 becomes

$$i = E_0 / [Z_i' + R]$$

This means that the transmission power becomes maximum at the resonance frequency.

In the above equation,

$$Z_{i'} = [|Z_2|^2 / (Z_i^2 + |Z_2|^2)]$$

Thus the reactance of  $Z_{i'}$  can be determined by the value of the inductor  $L_2$ . This means that the matching with transmission/reception circuit 3 in terms of the reactance at the resonance frequency  $f_r$  can be adjusted by adjusting the position of the connection tap. More specifically, the position of the connection tap is adjusted so that the above-described reactance is cancelled at the resonance frequency  $f_r$ .

In the construction described above, if the pager is formed not in the form such as that shown in Fig. 14 but in a thin card-shaped structure with a thickness of 1 to 3 mm, an apparent reduction in the inductance of the loop antenna 2' occurs due to a stray capacitance which is produced when the pager is in close proximity to a human body, in particular when the pager is held by a hand. As a result, resonance no longer occurs at the specified frequency, and a reduction occurs in the current flowing through the circuit.

One known technique to solve the above problems is to employ a loop antennal structure such as that disclosed in Japanese Examined Patent Publication No. 5-24693. Figs. 17, 18, and 19 are schematic diagrams illustrating the conventional loop antenna disclosed in Japanese Examined Patent Publication No. 5-24693, wherein Fig. 17 is a perspective view illustrating the appearance of a loop antenna 2' formed in the shape of a card, Fig. 18 is a cross-sectional view of the loop antenna 2' seen from a side, and Fig. 19 is an equivalent electric circuit of the loop antenna 2'.

In Figs. 17-19, similar parts to those in Fig. 14 are denoted by similar reference numerals. Reference numerals 21-24

of Fig. 19 denote equivalent electrical elements including inductances and loss resistances corresponding to the physical elements shown in Fig. 17 including an upper metal sheet 21' of the card-shaped loop antenna 2', a slotted side metal sheet 22', a bottom metal sheet 23', and a bent side metal sheet 24'. Furthermore, in Fig. 19, reference numeral 220 denotes a capacitor mainly associated with a slit 220'.

Now the operation will be described below. The loop antenna 2' operates in a similar manner to that of Fig. 14. However, as opposed to the loop antenna shown in Fig. 14, the loop antenna 2' shown in Fig. 17 is formed by bending twice a large-size metal sheet into a C-like shape so that the capacitance associated with the slit becomes sufficiently large compared with the stray capacitance which occurs when the card is held by a human user thereby ensuring that the resonance frequency is less influenced by the human body.

However, if the thickness is reduced, the area of the C-like cross-section of the loop area decreases and thus it becomes impossible to obtain a large enough induced voltage  $E_0$ .

Another technique to suppress the influence of the human body on the change in the resonance frequency is disclosed in Japanese Examined Patent Publication No. 4-6123. Figs. 20 and 21 illustrate the conventional loop antenna disclosed in Japanese Examined Patent Publication No. 4-6123, wherein Fig. 20 illustrates the structure of the loop antenna, and Fig. 21 illustrates an equivalent electric circuit of the loop antenna shown in Fig. 20.

In Figs. 20 and 21, similar parts to those in Fig. 14 are denoted by similar reference numerals. In this example, the loop antenna 2' is made up of a material having a large relative

dielectric constant. Reference numerals 21A-21N denote equivalent electric elements such as inductance, capacitance, and resistance which are distributed across the structure of the high-permittivity dielectric loop antenna 2'.

The loop antenna 2' operates as follows. The operation is similar to that of the loop antenna shown Fig. 14 except that the resonance frequency of the loop antenna 2' is determined by the internal inductance and the capacitance which depends on the loop size of the antenna as well as the dielectric constant of the dielectric material. In this loop antenna 2', the use of a material having a high dielectric constant results in suppression of the influence of the human body on the change in the resonance frequency. The resonance frequency  $f_r$  of this loop antenna 2' is given as:

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{\pi\sqrt{\epsilon_0\epsilon_r d^2\mu_0\left[\frac{\mu_s}{4} + \ln\frac{8D}{d} - 2\right]}}$$

In the above equation,  $\epsilon_0$  is the dielectric constant of a vacuum,  $\epsilon_r$  is the relative dielectric constant of the loop antenna 2',  $d$  is the radius of the cross section of the loop antenna 2',  $\mu_0$  is the magnetic permeability of a vacuum,  $\mu_s$  is the relative permeability of the loop antenna 2', and  $D$  is the radius of the circle of the loop antenna 2'. As can be seen from the above equation, if the relative permeability  $\mu_s$  is large enough, the change in the resonance frequency can be suppressed within a small range even when the effective radius  $D$  of the loop antenna 2' is reduced as a result of the influence of a hand of a human user.

However, a common material having a high dielectric

constant such as ceramic is rigid and fragile, it is difficult to form the antenna into the shape of a card.

In the conventional techniques of transmission/reception apparatus such as those described above, some problems will occur when a transmission/reception apparatus is formed into a thin form like a card, as will be described below.

A first problem is that the resonance frequency is easily changed by the influence of a human body.

A second problems is that if the thickness of the case is reduced, the loop area becomes too small to obtain a large enough induced current.

A third problem is that the rigidity and fragility of the material of the antenna makes it difficult for the antenna to withstand strain in the structure (such as bending or torsion). Furthermore, the problems with the material make it difficult to produce a thin transmission/reception apparatus at low cost.

Accordingly, it is a general object of the present invention to solve the above problems. More specifically, it is an object of the present invention to eliminate the influence of a human body. It is another object of the present invention to reduce the thickness of the transmission/reception apparatus without producing the above problems.

In an aspect of the present invention, there is provided a receiving apparatus including: a case in which a receiver is housed; a loop antenna for receiving a radio wave, disposed in the case and connected to the above-described receiver; and a capacitive reactance element disposed in the

middle of a part between two predefined stray-capacitance-coupling points of the loop antenna so that the capacitive reactance element is inserted in a series fashion in the loop antenna, the capacitance of the capacitive reactance element being set so that resonance occurs in the above-described part between the two predefined stray-capacitance-coupling points at a predetermined resonance frequency.

A capacitor may be employed as the capacitive reactance element. The two points between which above-described part is located are selected so that stray capacitance is most likely to occur between the selected two points.

According to another aspect of the present invention, there is provided a receiving apparatus including: a case in which a receiver is housed; a loop antenna for receiving a radio wave, the loop antenna being disposed in the case and connected to the receiver, the loop antenna including a plurality of parts which are long in distance to a wall of said case and also including a plurality of parts which are short in said distance compared to said long parts, said plurality of short parts being defined as those parts between stray-capacitance-coupling points; and capacitive reactance elements each disposed in the middle of the respective parts between the stray-capacitance-coupling points so that the capacitive reactance elements are inserted in a series fashion in the loop antenna, the capacitances of the capacitive reactance elements being set so that resonance occurs at a redetermined resonance frequency in each of the above-described parts between the stray-capacitance-coupling points.

In this apparatus, a capacitor may also be employed as the capacitive reactance element.

The "wall" of the case refers to the outer wall of the

case which a human body can come into contact with. In more rigorous definition, when the case is placed in such a manner that the greatest-area face of the thin case comes in the upper or lower surface position, the "wall" of the case refers to a side face of the case. The predetermined resonance frequency may be selected to a value within a frequency band the frequency of a radio wave to be received falls in. The "long part" refers to such a part which is longer in distance to the wall of the case than the "shorter parts". In other words, the loop antenna has various parts which are different in distance to the wall of the case.

According to still another aspect of the present invention, there is provided a receiving apparatus including: a case in which a receiver is housed; a loop antenna for receiving a radio wave, the loop antenna being disposed in the case and connected to the receiver, the loop antenna including a plurality of parts which are long in distance to a wall of said case and also including a plurality of parts which are short in said distance compared to said long parts, said plurality of short parts being defined as those parts between stray-capacitance-coupling points; and capacitive reactance elements each disposed in the middle of the respective parts between the stray-capacitance-coupling points so that the capacitive reactance elements are inserted in a series fashion in the loop antenna, the capacitances of the capacitive reactance elements being set so that resonance occurs at a predetermined resonance frequency in each of the above-described parts between the stray-capacitance-coupling points.

The term "center" is used here to describe such a point which is located at the center in length of the part between the predefined two stray-capacitance-coupling points.

Preferably, the loop antenna is formed in the shape of a polygon having vertices disposed near the wall of the case and also having vertices disposed far from the wall of the, wherein the capacitive reactance element is disposed at the vertices far from the wall of the case, and the capacitance of the capacitive reactance element is set so that resonance occur in the part between the vertices near the wall of the case at the predetermined frequency.

The vertices disposed near the wall of the case are such the points defined in the first or second aspect of the present invention as the stray-capacitance-coupling points. The vertices at the stray-capacitance-coupling points and the vertices where the capacitive reactance element is disposed are arranged in an alternating fashion along the loop antenna.

Preferably, the case may be formed into the shape of a rectangular or a square, and the loop antenna may be formed into the shape of a circle.

According to still another aspect of the present invention, there is provided a receiving apparatus including: a case in which a receiver is housed; a substrate housed in the case; a first loop antenna for receiving a radio wave, the first loop antenna being disposed on one surface of the substrate and connected to the receiver; a second loop antenna for receiving the radio wave, the second loop antenna being disposed on the other surface of the substrate and connected to the receiver; a first sheet-shaped conductor disposed in the first loop antenna; and a second sheet-shaped conductor disposed in the second loop antenna, the second sheet-shaped conductor facing the first sheet-shaped conductor in such a manner as to produce capacitance between the first and second sheet-shaped conductors.

According to still another aspect of the present invention, there is provided a transmitting apparatus including: a case in which a transmitter is housed; a loop antenna for transmitting a radio wave, the loop antenna being disposed in the case and connected to the transmitter; and a capacitive reactance element disposed in the middle of a part between two predefined stray-capacitance-coupling points of the loop antenna so that the capacitive reactance element is inserted in a series fashion in the loop antenna, the capacitance of the capacitive reactance element being set so that resonance occurs in the above-described part between the two predefined stray-capacitance-coupling points at a predetermined resonance frequency.

In this apparatus, a capacitor may also be employed as the capacitive reactance element.

According to still another aspect of the present invention, there is provided a transmitting apparatus including: a case in which a transmitter is housed; a loop antenna for transmitting a radio wave, the loop antenna being disposed in the case and connected to the transmitter, the loop antenna including a plurality of parts which are long in distance to a wall of said case and also including a plurality of parts which are short in said distance compared to said long parts, said plurality of short parts being defined as those parts between stray-capacitance-coupling points; and capacitive reactance elements each disposed in the middle of the respective parts between the stray-capacitance-coupling points so that the capacitive reactance elements are inserted in a series fashion in the loop antenna, the capacitances of the capacitive reactance elements being set so that resonance occurs at a redetermined resonance frequency in each of the above-described

parts between the stray-capacitance-coupling points.

In this apparatus, a capacitor may also be employed as the capacitive reactance element. The "wall" of the case refers to the outer wall of the case which a human body can come into contact with. In more rigorous definition, when the case is placed in such a manner that the greatest-area face of the thin case comes in the upper or lower surface position, the "wall" of the case refers to a side face of the case. The predetermined resonance frequency may be selected to a value within a frequency band the frequency of a radio wave to be transmitted falls in. The "long part" refers to such a part which is longer in distance to the wall of the case than the "shorter part". In other words, the loop antenna has various parts which are different in distance to the wall of the case.

Preferably, the above-described capacitive reactance element is inserted in the middle of the part between the stray-capacitance-coupling points of the loop antenna so that the capacitive reactance element is inserted in a series fashion in the loop antenna, the capacitive reactance element being disposed at the center of the part between the stray-capacitance-coupling points.

The term "center" is used here to describe such a point which is located at the center in length of the part between the predefined two stray-capacitance-coupling points.

Preferably, the loop antenna is formed in the shape of a polygon having vertices disposed near the wall of the case and also having vertices disposed far from the wall of the case, wherein the capacitive reactance element is disposed at the vertices far from the wall of the case, and the capacitance of the capacitive reactance element is set so that resonance occur in the part between the vertices near the wall of the case at the

predetermined frequency.

The vertices disposed near the wall of the case are such the points defined in the seventh or eighth aspect of the present invention as the stray-capacitance-coupling points. The vertices at the stray-capacitance-coupling points and the vertices where the capacitive reactance element is disposed are arranged in an alternating fashion along the loop antenna.

Preferably, the case may be formed in the shape of a rectangular or a square, and the loop antenna may be formed in the shape of a circle.

According to a further aspect of the present invention, there is provided a transmitting apparatus including: a case in which a transmitter is housed; a substrate housed in the case; a first loop antenna for transmitting a radio wave, the first loop antenna being disposed on one surface of the substrate and connected to the transmitter; a second loop antenna for transmitting the radio wave, the second loop antenna being disposed on the other surface of the substrate and connected to the transmitter; a first sheet-shaped conductor disposed in the first loop antenna; and a second sheet-shaped conductor disposed in the second loop antenna, the second sheet-shaped conductor facing the first sheet-shaped conductor in such a manner as to produce capacitance between the first and second sheet-shaped conductors.

The invention is particularly advantageous in a slimline, e.g. thin or card-shaped, receiver or transmitter.

The invention will be further described by way of non-limitative example with reference to the accompanying drawings, in which:-

Figure 1 is a schematic diagram of a card-shaped transmission/reception apparatus according to a first embodiment of the present invention.

Figure 2 is a circuit diagram illustrating an equivalent

electric circuit of the card-shaped transmission/reception apparatus according to the first embodiment of the present invention.

Fig. 3 is a circuit diagram illustrating an equivalent electric circuit of the card-shaped transmission/reception apparatus according to the first embodiment of the present invention.

Fig. 4 is a schematic diagram illustrating the card-shaped transmission/reception apparatus according to the first embodiment of the present invention, wherein the apparatus is held by a hand.

Fig. 5 is a circuit diagram illustrating a simplified equivalent electric circuit of the card-shaped transmission/reception apparatus according to the first embodiment of the present invention.

Fig. 6 is a schematic diagram of a card-shaped transmission/reception apparatus according to a second embodiment of the present invention.

Fig. 7 is a schematic diagram of a card-shaped transmission/reception apparatus according to a third embodiment of the present invention.

Fig. 8 is a schematic diagram of a card-shaped transmission/reception apparatus according to a fourth embodiment of the present invention.

Fig. 9 is a schematic diagram of a card-shaped transmission/reception apparatus according to a fifth embodiment of the present invention.

Fig. 10 is a schematic diagram of a card-shaped transmission/reception apparatus according to a sixth embodiment of the present invention.

Fig. 11 is a schematic diagram of a card-shaped

transmission/reception apparatus according to a seventh embodiment of the present invention.

Fig. 12 is a schematic diagram of a card-shaped transmission/reception apparatus according to an eighth embodiment of the present invention.

Fig. 13 is a circuit diagram illustrating an equivalent electric circuit of the card-shaped transmission/reception apparatus according to the eighth embodiment of the present invention.

Fig. 14 is a schematic diagram of a transmission/reception apparatus according to a first conventional technique.

Fig. 15 is a plan view illustrating the transmission/reception apparatus according to the first conventional technique, developed on a plane.

Fig. 16 is a circuit diagram illustrating an equivalent electric circuit of the transmission/reception apparatus according to the first conventional technique.

Fig. 17 is a schematic diagram of a transmission/reception apparatus according to a second conventional technique.

Fig. 18 is a cross-section view of the transmission/reception apparatus according to the second conventional technique.

Fig. 19 is a circuit diagram illustrating an equivalent electric circuit of the transmission/reception apparatus according to the second conventional technique.

Fig. 20 is a schematic diagram of a transmission/reception apparatus according to a third conventional technique.

Fig. 21 is a circuit diagram illustrating an

equivalent electric circuit of the transmission/reception apparatus according to the third conventional technique.

### Embodiment 1

#### Description of the drawings

Fig. 1 is a top view of a card-shaped transmission/reception apparatus according to an embodiment of the present invention wherein a loop antenna and a transmission/reception circuit disposed in a case are seen through the upper wall of the case. In Fig. 1, reference numeral 1 denotes a card-shaped case and reference numeral 2 denotes a rectangular loop conductor disposed on a substrate housed in this card-shaped case 1, wherein the four vertices of the rectangle are denoted by symbols A-D, respectively. Thus, the loop conductor 2 has four sides each located between two vertices. Reference numeral 3 denotes a transmission/reception circuit connected to the loop conductor 2. The transmission/reception circuit receives a radio wave detected by the loop conductor 2 and also transmits a radio wave via the loop conductor 2. Reference numerals 11-14 denote capacitors disposed at the center of each side of the rectangular loop conductor 2. Reference numerals 31 and 32 denote lead wires which connect the loop conductor 2 to the transmission/reception circuit 3.

Fig. 2 illustrates an equivalent electric circuit of the card-shaped transmission/reception apparatus shown in Fig. 1. In Fig. 2, reference numerals similar to those in Fig. 1 denote equivalent or similar parts. Reference numerals 210-241 denote the equivalent electric element of the portion of the loop conductor 2 located at either side of each capacitor 11-14.

located at the center of each side of the loop conductor 2. That is, reference numeral 210 denotes loss resistance and inductive reactance which occur between the capacitor 11 and the vertex D. Similarly, reference numeral 211 denotes loss resistance and inductive reactance between the capacitor 11 and the vertex A, 220 between the capacitor 12 and the vertex A, 221 between the capacitor 12 and the vertex B, 230 between the capacitor 13 and the vertex B, 231 between the capacitor 13 and the vertex C, 240 between the capacitor 14 and the vertex C, and 241 between the capacitor 14 and the vertex D.

Fig. 3 illustrates an equivalent electric circuit in which elements on each side of the loop conductor 2 are combined into a simpler form. In Fig. 3, reference numerals similar to those in Fig. 1 denote equivalent or similar parts. Reference numeral 21 denotes an equivalent electric element consisting of a set of loss resistance and inductance obtained by combining two sets of loss resistance and inductance denoted by reference numerals 210 and 211 in Fig. 2. Similarly, reference numerals 22, 23, and 24 denotes equivalent electric elements each consisting of a set of loss resistance and inductance obtained by combining two sets of loss resistance and inductance denoted by reference numerals 220 and 221, 230 and 231, and 240 and 241, respectively.

Fig. 4 illustrates the card-shaped case 1 held by a hand, in which similar parts to those in Fig. 1 are denoted by similar reference numerals. Reference numeral 9 denotes a hand of a user. Reference 15 denotes a stray capacitance which occurs between the hand 9 and the vertex A of the loop conductor 2, and 16 denotes a stray capacitance which occurs between the hand 9 and the vertex B. In this specific example shown in Fig. 4, the user holds portions near the vertices A and B of the

rectangle, and thus the stray capacitance is produced between the hand and these vertices A and B. Although the portion where stray capacitance is produced varies with the position held by the hand of the user, it can be predicted that those portions near the vertices of the rectangle is most likely to be held by a user in practical use.

Fig. 5 illustrates an equivalent electric circuit of the card-shaped transmission/reception apparatus shown in Fig. 4. In Fig. 5, similar reference numerals to those in Fig. 3 denote similar parts. Reference numeral 17 denotes a stray capacitance  $C_{st}$  which occurs when the card-shaped case 1 is held by a hand in such a manner as shown in Fig. 4.

#### Description of the Operation

Now the operation will be described below. The resonance frequency associated with the loop conductor 2 is determined mainly by the inductive reactance 21-24 of the equivalent elements and the capacitive reactance of capacitors 11-14 shown in Fig. 3. These electric elements are designed so that resonance occurs at a predetermined resonance frequency at which the electric current flowing through the loop antenna becomes maximum. Accordingly, the capacitive reactance such as a capacitor 11 inserted in the loop conductor 2 is one of important factors which determine the resonance frequency. In the conventional techniques, in particular in the card-type loop antenna, the resonance frequency is affected by the stray capacitance  $C_{st}$  produced by a user's hand in close proximity to the loop conductor. This produces difficulty in transmission/reception operation at a desired frequency in the predefined frequency band. In contrast, in the present invention, the resonance frequency is much less influenced by the stray capacitance  $C_{st}$ , and thus nearly maximum current can

be obtained.

The basic concept of this embodiment 1 is in that the capacitors 11-14 are inserted in the respective sides of the loop conductor 2 having a polygon shape and the capacitance of each capacitor 11-14 is set so that resonance occurs on each side at a predetermined frequency (hereinafter referred to as a specified resonance frequency). For example, in the part between the vertices A and B, the capacitance of the capacitor 12 is set so that resonance occurs in that part at the specified resonance frequency. The specific capacitance required to meet the above condition can be derived from the inductance 22 present between vertices A and B. In this case, series resonance occurs in the series connection of the capacitor 12 and the inductance component of the equivalent electric element 22 between the vertices A and B, and thus a maximum current flows through this series path including the capacitor 12 without being influenced by the stray capacitance  $C_{st}$ . The capacitances of the capacitors on the other sides are set in a similar manner so that resonance occurs at the same specified resonance frequency on each side and a maximum current can flow through over the whole loop conductor 2 at the resonance frequency.

The above operation will be described in further detail below.

In general, the inductance  $L$  of the loop conductor 2 taking into account the mutual interaction among different lines can be given as:

$$L = \frac{4[(a+b)\ln(2ab/r) - a\ln(a+b) - b\ln(b+d) - P(a+b) + 2(d+r)]}{10^{-9}} [H]$$

where "a" is the length of long sides, "b" is the length of short sides,  $r$  is the radius of the loop conductor 2 which is assumed to have a single wire structure,  $d = [a^2 + b^2]^{1/2}$  (centimeter), and  $P$  is the shape factor in the range of 1.75 to 2.

From the above equation, it can be seen that the inductance on each side is substantially proportional to its length. If the inductances of the respective equivalent electric elements 210, 211, 220, 221, 230, 231, 240 and 241 are represented by  $L_{210}$ ,  $L_{211}$ ,  $L_{220}$ ,  $L_{221}$ ,  $L_{230}$ ,  $L_{231}$ ,  $L_{240}$  and  $L_{241}$ , then

$$L_{210} = L_{211} = L_{230} = L_{231} = L[a/(4(a+b))] = La$$

$$L_{220} = L_{221} = L_{240} = L_{241} = L[b/(4(a+b))] = Lb$$

In order that the impedances between the vertices A and B and also between the vertices C and D, between which stray capacitance is produced when the card-shaped case 1 is held by a hand, become zero at the specified resonance frequency, the capacitances  $C_{12}$  and  $C_{14}$  of the capacitors 12 and 14 should be:

$$C_{12} = C_{14} = 1/(2\omega r^2 Lb)$$

where  $\omega r = 2\pi fr$ .

Similarly, if the input impedance of the transmission/reception circuit 3 is neglected, the capacitances  $C_{11}$  and  $C_{13}$  of the capacitors 11 and 12 on the long sides are given by:

$$C_{11} = C_{13} = 1/(2\omega r^2 La)$$

When the input impedance of the transmission/reception circuit is given as  $Z_i = R_i$ , the effect thereof can be taken into account as follows. The parallel connection of  $R_i$  and  $C_{11}$  can be represented by an equivalent series connection of  $R_i'$  and  $C_{11}'$  wherein  $R_i'$  and  $C_{11}'$  are given as:

$$R_i' = \frac{R_i}{1 + \frac{R_i^2}{|Z_{C_{11}}|^2}}$$

$$C_{11}' = C_{11} \left[ 1 + \frac{|Z_{C_{11}}|^2}{R_i^2} \right]$$

where

$$|Z_{C_{11}}| = \frac{1}{\omega_r C_{11}}$$

Thus, the capacitance  $C_1$  which should actually be disposed at the location of  $C_{11}$  can be determined from the following equation.

$$C_{11} = \frac{C_1}{1 + \frac{|Z_{C_{11}}|^2}{R_i^2}}$$

Thus

$$C_1 = \frac{C_{11}}{1 + \frac{|Z_{C_{11}}|^2}{R_i^2}}$$

From the above discussion, the resonance current which flows at the specified resonance frequency can be given by:

$$I_r = \frac{e_o}{R_i + R + Z_{AB} // Z_{ST} + Z_{AD} + Z_{BC} + Z_{CD}}$$

where

$$Z_{AB} = j \left( 2\omega_r L_b - \frac{1}{\omega_r C_{12}} \right)$$

$$Z_{AD} = j \left( 2\omega_r L_a - \frac{1}{\omega_r C'_{11}} \right)$$

$$Z_{BC} = j \left( 2\omega_r L_c - \frac{1}{\omega_r C_{13}} \right)$$

$$Z_{CD} = j \left( 2\omega_r L_b - \frac{1}{\omega_r C_{14}} \right)$$

In the above equation, R is the overall resistance equivalent to the combination of four loss resistances of the equivalent electric elements 21-24. In this case, since all the four loss resistances are connected in series, the overall resistance can be determined easily.  $Z_{AB}$  is impedance due to the inductive reactance present between the vertices A and B. Similarly,  $Z_{AD}$ ,  $Z_{BC}$  and  $Z_{CD}$  are impedances due to the inductive reactance present between the vertices A and D, between B and C, and between C and D, respectively.

At the specified resonance frequency,  $Z_{AB} = 0$ , and thus the stray capacitance does not have any influence on the resonance.

Furthermore, at the specified resonance frequency,  $Z_{BC} = Z_{AD} = Z_{CD} = 0$ , and thus a maximum electric current flows

through the loop conductor 2.

As described above, even if stray capacitance  $C_{st}$  is produced when a pair of some vertices A-D are held with a hand of a user, resonance can occur in the part between the above pair of vertices where the stray capacitance  $C_{st}$  is produced and thus no degradation in the sensitivity of the transmission or reception occurs.

Furthermore, since the resonance circuit is composed of a plurality of capacitors disposed on the respective sides or between the respective pairs of vertices, it is possible to easily accomplish fine adjustment of the resonance frequency and correction of the temperature characteristic thereof. As a result, a greater degree of freedom is allowed in the design. Furthermore, in production, a greater tolerance in terms of the characteristic of the loop conductor is allowed.

Furthermore, in the present embodiment, since the resonance circuit is formed in such a manner that resonance occurs on each side, it is easy to achieve optimum matching with the transmission/reception circuit by selecting a proper value of capacitance. This allows a reduction in the number of components constituting the matching circuit.

## Embodiment 2

In this second embodiment, the loop conductor is formed in the shape of a rhombus thereby suppressing the change in the resonance frequency more effectively.

Fig. 6 is a top view of a card-shaped transmission/reception apparatus according to the second embodiment. In Fig. 6, the same reference numerals as those in Fig. 1 denote the equivalent or similar parts. 2a denotes a loop conductor in the form of a rhombus whose vertices are

located near the respective four sides of a card-shaped case 1.

In this second embodiment, the fundamental construction and operation are similar to those of the first embodiment, and thus only those different from the first embodiment will be described below.

In this loop conductor 2a, vertices A and B are located near the respective long sides of the card-shaped case 1. The purpose of the above arrangement is to suppress the influence of the stray capacitances 15 and 16, which will be produced near the sides of the card-shaped conductor 1 when held with a hand 9 of a user, on the resonance frequency. When the card-shaped transmission/reception apparatus is held by the user, it is most likely that two opposite sides of the card-shaped case 1 are held. The stray capacitances 15 and 16 produced by the hand 9 increase with the reduction in the distance between the hand 9 and the loop conductor 2a. For the above two reasons, the disturbance in the resonance frequency due to the stray capacitances 15 and 16 is most likely occur on the sides of the card-shaped case 1, and such the disturbance will result in a great change in resonance frequency. In the present invention, as described earlier with reference to the first embodiment, when the stray capacitances 15 and 16 are produced near the vertices A and B, no great disturbance occurs in the resonance frequency. Thus, if the vertices A and B are located near the respective sides, it is possible to suppress the change in the resonance frequency due to the stray capacitances produced on the sides.

However, in this arrangement, if the stray capacitances 15 and 16 are coupled with the loop conductor 2a via points other than vertices A and B, the change in the resonance frequency increases with the distance between the

vertex A or B and the points via which the stray capacitances are coupled, since the inductance between the points where the stray capacitances 15 and 16 are connected in parallel changes with the above distance and thus the resonance frequency also changes with the distance.

In this second embodiment, the above problem is avoided by arranging the loop conductor 2 in such a manner that portions other than the vertices A and B are located not near the four sides of the card-shaped case 1 but far from them. In this arrangement, when any of the four sides is held with a hand, the resultant stray capacitances 15 and 16 will be small enough since the loop conductor 2a is far from the four sides. Thus, the present invention provides a card-shaped transmission/reception apparatus which is excellent in stability of the resonance frequency without being disturbed by the stray capacitances 15 and 16.

In particular, in this arrangement, the distance of a point on the card-shaped conductor 2a relative to the card-shaped case 1 increases with the location of that point measured in distance from the vertex A or B toward the capacitance 12. Therefore those portions which are more sensitive to the stray capacitances 15 and 16 will have less stray capacitance.

The areas on the short sides facing a human body are reduced so that the short sides become more insensitive to the stray capacitances. Furthermore, the capacitances 12 and 14 and the inductances on the respective sides are selected so that the impedance seen from a vertex on either long side which is sensitive to the stray capacitances becomes zero at the specified resonance frequency. This prevents the reduction in the receiving sensitivity due to the change in the resonance frequency when the transmission/reception apparatus is placed

near a human body.

### Embodiment 3

In this third embodiment, the loop conductor is formed in the shape of a polygon such as that shown in Fig. 7 thereby suppressing the change in the resonance frequency more effectively.

Fig. 7 is a top view of a card-shaped transmission/reception apparatus 1 according to the third embodiment. In Fig. 7, the same reference numerals to those in Fig. 1 or 6 are used to denote the equivalent or similar parts. Reference symbol 2b denotes an octagonal loop conductor whose vertices are located near the four sides of a rectangular card-shaped case 1.

In this third embodiment, the fundamental construction and operation are similar to those of the second embodiment, and thus only those different from the second embodiment will be described below.

In this third embodiment, the loop conductor 2b has a greater number of vertices A, B, C and D than that of the second embodiment, and the form of the loop conductor 2b is improved to increase the area surrounded by the loop conductor 2b. This results in an increase in the voltage induced in the loop conductor 2b in the receiving operation and thus the receiving sensitivity is improved.

In the parts of the conductor between the vertices A and D and between B and D, the capacitors 12 and 13 are located far from any of the four sides of the card-shaped case thereby reducing the stray capacitances 15 and 16 produced by a hand 9. As a result, in the card-shaped transmission/reception apparatus according to this embodiment, not only the vertices A, B, C and

D but also the other parts along the whole conductor are less susceptible to disturbances, which results in a smaller change in the resonance frequency. Thus, as in the previous embodiments, it is possible to realize a card-shaped transmission/reception apparatus having a good receiving sensitivity.

#### Embodiment 4

In this fourth embodiment, the loop conductor is formed in the shape of a polygon such as that shown in Fig. 8 thereby increasing the number of vertices so that the resonance frequency becomes less sensitive to the stray capacitances 15 and 16 and thus the change in the resonance frequency is suppressed more effectively.

Fig. 8 is a top view of a card-shaped transmission/reception apparatus 1 according to the fourth embodiment. In Fig. 8, the same reference numerals to those in Fig. 1 or 7 are used to denote the equivalent or similar parts. Reference symbol 2c denotes a loop conductor having sixteen vertices located near the four sides of a rectangular card-shaped case 1. Capacitors 11a-11c corresponding to the capacitor 11 shown in Fig. 7 are disposed in the middle of parts between the vertices D and H, between H and E, and between E and A, respectively. The capacitances of these capacitors 11a-11c are set so that each capacitance in conjunction with the inductance present between the corresponding vertices results in a resonance frequency equal to the specified value fr. Similarly, capacitors 13a-13c corresponding to the capacitor 13 shown in Fig. 7 are disposed in the middle between the vertices C and G, between G and F, and between F and B, respectively.

In this fourth embodiment, the fundamental

construction is similar to that of the third embodiment and thus its function and operation are also similar to those of the third embodiment. Therefore, only those different from the third embodiment will be described below.

In this fourth embodiment, the loop conductor 2b has a greater number of vertices A to H than that of the third embodiment, and the form of the loop conductor 2b is improved to further increase the area surrounded by the loop conductor 2b thereby further increasing the voltage induced in the loop conductor 2b in the receiving operation and thus further increasing the receiving sensitivity.

In particular, the increase in the number of vertices A-H to as many as eight results in a corresponding increase in the number of parts which are insensitive to the stray capacitances 15 and 16, and thus the change in the resonance frequency can be prevented more effectively.

#### Embodiment 5

In this fifth embodiment, the case has a square card form and the loop conductor has a circular form.

Fig. 9 is a top view of a card-shaped transmission/reception apparatus 1 according to the fifth embodiment 5. In Fig. 9, the same reference numerals as those in Fig. 7 are used to denote the equivalent or similar parts. Reference symbol 1a denotes a square card-shaped case, and 2d denotes a circular loop conductor whose vertices A-D are disposed near the respective four sides of the card-shaped case 1a, wherein the vertices A-D refers to those points of the loop conductor located nearest to any of the four sides of the card-shaped case 1a. The inductances between vertices A and B, between B and C, between C and D, and between D and A as well as

the capacitors 11 to 14 corresponding to the respective inductances are selected so that resonance occurs at the specified resonance frequency as in the previous embodiments.

In this fifth embodiment, therefore, the fundamental construction is similar to that of any of the previous embodiments, for example the third embodiment, and thus its function and operation are also similar to those of the previous embodiments. Therefore, only those different from the previous embodiments will be described below.

In this fifth embodiment, the vertices A-D are located near the respective four sides of the card-shaped case 1a. As described above with reference to the third embodiment, those sides are most likely places where stray capacitances 15 and 16 occur. Thus, it is required to suppress the influence of such the stray capacitances on the resonance frequency.

The above-described arrangement according to the present embodiment is effective to suppress the change in the resonance frequency.

Although in this fifth embodiment, the case is formed in the shape of a square card and the loop conductor is formed in the shape of a circle, the case may also be formed in the shape of a rectangle and the loop conductor may be formed in the shape of an ellipse.

#### Embodiment 6

In this sixth embodiment, a loop conductor having a square form is employed and its four vertices A-D are located near the respective four sides of a card-shaped case.

Fig. 10 is a top view of a card-shaped transmission/reception apparatus 1 according to the sixth embodiment. In Fig. 10, the same reference numerals as those in

Fig. 9 are used to denote the equivalent or similar parts. Reference symbol 2e denotes a square loop conductor whose vertices A-D are disposed near the respective four sides of the card-shaped case 1a.

In this sixth embodiment, the fundamental construction is similar to that of the fifth embodiment and thus its function and operation are also similar to those of the fifth embodiment. Therefore, the change in the resonance frequency can be suppressed effectively.

Thus, the loop conductor 2e is not limited to the circular shape as in the fifth embodiment but it may be formed in the shape of a square.

Furthermore, the loop conductor 2e may also be formed not in the shape of a square but a rectangular or other shapes as in the previous embodiments described above.

In this embodiment, as in the second embodiment, the loop conductor 2e is disposed in such a manner that the vertices of the loop conductor 2e are located near the center of the respective sides of the card-shaped case 1a thereby reducing the area facing a human body and thus reducing the influence of the stray capacitances 15 and 16.

Furthermore, the loop conductor 2e does not pass through any of the four corners of the card-shaped case. This arrangement results in reductions in the stray capacitances 15 and 16 which will be produced when the upper and lower surfaces at a certain corner of the card-shaped case 1a are held by fingers of a user as shown in Fig. 10. As a result, the change in the resonance frequency is prevented. This structure is particularly useful in applications in which any of the four corners is frequently held. This is also the case in the embodiments in which any of the parts 2a-2d of the card-shaped

conductor does not pass through any of the four corners.

#### Embodiment 7

In this seventh embodiment, a loop conductor having the shape shown in Fig. 11 is employed.

Fig. 11 is a top view of a card-shaped transmission/reception apparatus according to the seventh embodiment. In Fig. 11, the same reference numerals as those in Fig. 9 are used to denote the equivalent or similar parts. Reference numeral 1 denotes a rectangular card-shaped case. Reference numeral 2f denotes the loop conductor including two circular parts which are inscribed with the respective two short sides of the rectangular card-shaped case wherein the two circular parts are connected to each other via parallel conductor parts.

In this seventh embodiment, the fundamental construction is similar to that of the fifth embodiment except that the loop conductor 2f is formed into a different shape and thus its function and operation are also similar to those of the fifth embodiment. Therefore, the change in the resonance frequency can be suppressed effectively.

#### Embodiment 8

In this eighth embodiment, a loop conductor is provided on either sides of a substrate in such a manner as to create a large capacitance. Furthermore, a large loop area can be achieved in the present embodiment.

Fig. 12 is a top view of a card-shaped transmission/reception apparatus according to the eighth embodiment (wherein the upper surface is shown). In Fig. 12, the same reference numerals as those in Fig. 1 are used to

denote the equivalent or similar parts. Reference numeral 100 denotes a substrate on both sides of which the loop conductor is disposed. Reference numeral 2g denotes the loop conductor disposed on both sides of the substrate 100. Reference symbols A-D denote four vertices of the loop conductor 2g located on the upper surface of the substrate 100 while reference symbols A'-D' denote four vertices of the loop conductor 2g located on the lower surface of the substrate 100.

The pattern of the loop conductor 2g on the upper surface is similar to that on the lower surface. These two patterns on the upper and lower surfaces face each other via the substrate 100 made up of an insulating material. This structure can serve as a capacitor having a large capacitance. In the card-shaped transmission/reception apparatus according to the present embodiment, the loop conductor 2g has large-size portions near the short sides of the case which are often touched by a hand, so that greater capacitances are produced in such the areas.

The parts of the loop conductor 2g located near the long sides of the case are formed in the shape of a meandering line so as to increase the area of the loop and also to achieve a proper inductance. A resonance capacitor is inserted at the center of each of these parts on both sides. Since the above arrangement includes large capacitances, it is required that the loop conductor 2g should have a large inductance corresponding to the large capacitances so that resonance occurs at the specified resonance frequency. To meet the above requirement, the long-side portions of the loop conductor 2g of the present embodiment are formed in the shape of a meandering line thereby achieving a large inductance.

Fig. 13 illustrates an equivalent electric circuit of

the card-shaped transmission/reception apparatus shown in Fig. 12, in which the same reference numerals as those in Fig. 12 denote the same parts. Reference numeral 100 denotes resistance and capacitance associated with the large-area parts disposed between the vertices A and B and between A' and B' of the loop conductor 2g. Similarly, reference numeral 140 denotes resistance and capacitance associated with the large-area parts disposed between the vertices C and D and between C' and D' (hereinafter the term "large-area parts" is used to generically represent all the large-area parts between A and B, A' and B', C and D, and C' and D'). Reference numeral 17 denotes a stray capacitance which will be produced when a human user holds the card-shaped case 1 at a portion near a short side.

On either side of the substrate 100, there is provided a large-area portion extending over the whole length of each short side so as to produce a capacitor having a large enough capacitance compared with the stray capacitance 17 which will be created when a short-side portion is held between fingers of the user, thereby minimizing the influence of the stray capacitance 17.

There are also provided capacitors 12 and 14 connected in parallel to the respective capacitors formed with the large-area parts of the conductor disposed at the short sides. These capacitors 12 and 14 are used to adjust the resonance frequency.

The capacitances 11 and 13 are selected so that the impedance between the large-area parts disposed on each surface on the respective short sides becomes zero and also so that the overall impedance associated with the whole circuit becomes zero at the resonance frequency.

The loop antenna 2' operates as follows.

When the card-shaped case 1 is held by a hand, a stray

capacitance 17 is be produced between A and B, C and D, A' and B', and C' and D'. The stray capacitance 17 can cause a change in the resonance frequency. However, the loop conductor 2g has the large-area parts with a large capacitance disposed on the respective short sides, the change in the total capacitance caused by the stray capacitance 17 is small enough to suppress the change in the resonance frequency within an allowable small range. That is, the stray capacitance 17 is negligibly small compared with the overall capacitance of the loop conductor 2g, and thus the change in the resonance frequency can be suppressed within the small range.

In general, when a capacitor consisting of opposing plates each having an area S apart from each other by distance t is given, the capacitance thereof is written as  $C = \mu_s \mu_0 S/t$  where  $\mu_s$  is the relative dielectric constant and  $\mu_0$  is the dielectric constant in air.

Furthermore, the resonance frequency is not disturbed regardless of the manner in which the card-shaped case 1 held by a hand. For example, even when the card-shaped case 1 is held in such a manner that the upper and lower surfaces near a short side are held between fingers, no significant change in the resonance frequency occurs.

Furthermore, as opposed to the conventional technique 2, the area surrounded by the loop conductor can be sufficiently large to obtain a large induced voltage  $E_0$ .

Although in the above specific example capacitors having a large enough capacitance compared with the stray capacitance are formed with a large-area conductor near the respective short sides thereby preventing the influence of a human body, a high-permittivity dielectric resonator having a resonance frequency equal to the specified frequency may also be

disposed on either short side instead of the large-area conductor. In this case, the stray capacitance created by a human body in close proximity is absorbed by the high-permittivity dielectric resonator, and thus no significant change in the resonance frequency occurs.

Alternatively, instead of the large-area conductor, a great number of capacitors may be disposed on either short sides so that the stray capacitance produced by the human body in close proximity is absorbed by the great number of capacitors.

In this embodiment, capacitors can be produced easily by properly disposing the loop conductor on either side of the substrate. This allows a reduction in the number of capacitors and also allows a reduction in the thickness of the card-shaped apparatus.

Although in the specific embodiment described above, the large-area parts of the conductor are disposed on the respective short sides of the rectangular case 1, the large-area parts may also be disposed on the respective long sides to suppress the change in the resonance frequency caused by the stray capacitance.

Furthermore, although in the embodiment described above, the loop conductor 2g is disposed on both sides of the substrate 100, the loop conductor may also be disposed at an intermediate level of a multilayer substrate.

The invention has been described in detail above with reference specific embodiments. As can be seen from the above description, the invention has the following advantages.

In the thin receiving apparatus in one aspect of the invention, the apparatus includes: a thin case in which a receiver is housed; a loop antenna for receiving a radio wave, disposed in the case and connected to the above-described

receiver; and a capacitive reactance element disposed in the middle of a part between two predefined stray-capacitance-coupling points of the loop antenna so that the capacitive reactance element is inserted in a series fashion in the loop antenna, the capacitance of the capacitive reactance element being set so that resonance occurs in the above-described part between the two predefined stray-capacitance-coupling points at a predetermined resonance frequency. With this arrangement, in the part between the predefined stray-capacitance-coupling points, resonance can occur at the specified resonance frequency in that part consisting of a capacitive reactance and the inductive reactance present between the stray-capacitance-coupling points. This arrangement suppress the change in the resonance frequency which otherwise occur due to the stray capacitance created when the case is touched by some substance or is placed in close proximity to some substance, and thus the reduction in the receiving sensitivity can be prevented.

In the thin receiving apparatus in another aspect of the invention, the apparatus includes: a thin case in which a receiver is housed; a loop antenna for receiving a radio wave, the loop antenna being disposed in the case and connected to the receiver, the loop antenna including a plurality of parts which are long in distance to a wall of said case and also including a plurality of parts which are short in said distance compared to said long parts, said plurality of short parts being defined as those parts between stray-capacitance-coupling points; and capacitive reactance elements each disposed in the middle of the respective parts between the stray-capacitance-coupling points so that the capacitive reactance elements are inserted in a series fashion in the loop antenna, the capacitances of the capacitive reactance elements being set so that resonance occurs

at a redetermined resonance frequency in each of the above-described parts between the stray-capacitance-coupling points. With this arrangement, it is possible to minimize the influence of the stray capacitance which will be coupled in a parallel fashion to the capacitive and inductive reactance in the part between the predefined stray-capacitance-coupling points. In particular, the parts which are short in length to the wall of the case are likely to encounter a large stray capacitance. The arrangement of the embodiment can suppress the influence of the stray capacitance coupled to such the parts. On the other hand, the other parts are designed to have a long distance to the wall of the case so that the stray capacitance coupled to these parts is minimized. This allows suppression in the change in the resonance frequency even when some of the long parts other than those parts between the stray-capacitance-coupling points is held by a hand.

As a result, this arrangement more effectively suppress the change in the resonance frequency which otherwise occur due to the stray capacitance created when the case is touched by some substance or is placed in close proximity to some substance, and therefore no significant reduction in the receiving sensitivity occurs.

In a preferable mode, the above-described capacitive reactance element is inserted in the middle of the part between the stray-capacitance-coupling points of the loop antenna so that the capacitive reactance element is inserted in a series fashion in the loop antenna, wherein the capacitive reactance element is disposed at the center of the part between the stray-capacitance-coupling points. In this arrangement, since the capacitive reactance element is located at the center of the above part, the inductive reactance component of the loop

antenna present at one side of the capacitive reactance element is balanced with the inductive reactance component present at the other side of the capacitive reactance element. Thus, this arrangement more effectively suppress the change in the resonance frequency and thus prevents the reduction in the receiving sensitivity.

In another preferable mode, the loop antenna is formed in the shape of a polygon having vertices disposed near the wall of the case and also having vertices disposed far from the wall of the, wherein the capacitive reactance element is disposed at the vertices far from the wall of the case, and the capacitance of the capacitive reactance element is set so that resonance occur in the part between the vertices near the wall of the case at the predetermined frequency. This arrangement more effectively suppress the change in the resonance frequency which otherwise occur due to the stray capacitance created when the case is touched by some substance or is placed in close proximity to some substance, and therefore no significant reduction in the receiving sensitivity occurs.

Preferably, the above-described case may be formed into the shape of a rectangular or a square, and the loop antenna may be formed into the shape of a circle. This arrangement effectively suppress the change in the resonance frequency which otherwise occur due to the stray capacitance created when the case is touched by some substance or is placed in close proximity to some substance, and therefore no significant reduction in the receiving sensitivity occurs.

In the thin receiving apparatus in another aspect of the invention, the apparatus includes: a thin case in which a receiver is housed; a substrate housed in the case; a first loop antenna for receiving a radio wave, the first loop antenna being

disposed on one surface of the substrate and connected to the receiver; a second loop antenna for receiving the radio wave, the second loop antenna being disposed on the other surface of the substrate and connected to the receiver; a first sheet-shaped conductor disposed in the first loop antenna; and a second sheet-shaped conductor disposed in the second loop antenna, the second sheet-shaped conductor facing the first sheet-shaped conductor in such a manner as to produce capacitance between the first and second sheet-shaped conductors. In this arrangement, the loop antenna is formed with the first and second loop antennas in such a manner as to have a large area surrounded by the loop antenna thereby achieving a large induced voltage. Furthermore, a large capacitance is created between the first and second sheet-shaped conductors. This makes it possible to suppress the influence of the stray capacitance with a small number of components having a small volume. As a result, it is possible to produce a thin receiving apparatus having a reduced overall size.

In the thin transmitting apparatus according to still another aspect of the present invention, the apparatus includes: a thin case in which a transmitter is housed; a loop antenna for transmitting a radio wave, the loop antenna being disposed in the case and connected to the transmitter; and a capacitive reactance element disposed in the middle of a part between two predefined stray-capacitance-coupling points of the loop antenna so that the capacitive reactance element is inserted in a series fashion in the loop antenna, the capacitance of the capacitive reactance element being set so that resonance occurs in the above-described part between the two predefined stray-capacitance-coupling points at a predetermined resonance frequency. With this arrangement, in the part between the

predefined stray-capacitance-coupling points, resonance can occur at the specified resonance frequency in that part consisting of a capacitive reactance and the inductive reactance present between the stray-capacitance-coupling points. This arrangement suppress the change in the resonance frequency which otherwise occur due to the stray capacitance created when the case is touched by some substance or is placed in close proximity to some substance, and thus the reduction in the receiving sensitivity can be prevented.

In the thin transmitting apparatus according to a further aspect of the present invention, the apparatus includes: a thin case in which a transmitter is housed; a loop antenna for transmitting a radio wave, the loop antenna being disposed in the case and connected to the transmitter, the loop antenna including a plurality of parts which are long in distance to a wall of said case and also including a plurality of parts which are short in said distance compared to said long parts, said plurality of short parts being defined as those parts between stray-capacitance-coupling points; and capacitive reactance elements each disposed in the middle of the respective parts between the stray-capacitance-coupling points so that the capacitive reactance elements are inserted in a series fashion in the loop antenna, the capacitances of the capacitive reactance elements being set so that resonance occurs at a predetermined resonance frequency in each of the parts between the stray-capacitance-coupling points. With this arrangement, it is possible to minimize the influence of the stray capacitance which will be coupled in a parallel fashion to the capacitive and inductive reactance in the part between the predefined stray-capacitance-coupling points. In particular, the parts which are short in length to the wall of the case are

likely to encounter a large stray capacitance. The arrangement of the embodiment can suppress the influence of the stray capacitance coupled to such the parts. On the other hand, the other parts are designed to have a long distance to the wall of the case so that the stray capacitance coupled to these parts is minimized. This allows suppression in the change in the resonance frequency even when some of the long parts other than those parts between the stray-capacitance-coupling points is held by a hand.

As a result, this arrangement more effectively suppress the change in the resonance frequency which otherwise occur due to the stray capacitance created when the case is touched by some substance or is placed in close proximity to some substance, and therefore no significant reduction in the receiving sensitivity occurs.

In a preferable mode, the above-described capacitive reactance element is inserted in the middle of the part between the stray-capacitance-coupling points of the loop antenna so that the capacitive reactance element is inserted in a series fashion in the loop antenna, wherein the capacitive reactance element is disposed at the center of the part between the stray-capacitance-coupling points. In this arrangement, since the capacitive reactance element is located at the center of the above part, the inductive reactance component of the loop antenna present at one side of the capacitive reactance element is balanced with the inductive reactance component present at the other side of the capacitive reactance element. Thus, this arrangement more effectively suppress the change in the resonance frequency and thus prevents the reduction in the receiving sensitivity.

In another preferable mode, the loop antenna is formed

in the shape of a polygon having vertices disposed near the wall of the case and also having vertices disposed far from the wall of the, wherein the capacitive reactance element is disposed at the vertices far from the wall of the case, and the capacitance of the capacitive reactance element is set so that resonance occur in the part between the vertices near the wall of the case at the predetermined frequency. This arrangement more effectively suppress the change in the resonance frequency which otherwise occur due to the stray capacitance created when the case is touched by some substance or is placed in close proximity to some substance, and therefore no significant reduction in the receiving sensitivity occurs.

Preferably, the above-described case may be formed into the shape of a rectangular or a square, and the loop antenna may be formed into the shape of a circle. This arrangement effectively suppress the change in the resonance frequency which otherwise occur due to the stray capacitance created when the case is touched by some substance or is placed in close proximity to some substance, and therefore no significant reduction in the receiving sensitivity occurs.

In the thin transmitting apparatus in another aspect of the invention, the apparatus includes: a thin case in which a transmitter is housed; a substrate housed in the case; a first loop antenna for transmitting a radio wave, the first loop antenna being disposed on one surface of the substrate and connected to the transmitter; a second loop antenna for transmitting the radio wave, the second loop antenna being disposed on the other surface of the substrate and connected to the transmitter; a first sheet-shaped conductor disposed in the first loop antenna; and a second sheet-shaped conductor disposed in the second loop antenna, the second sheet-shaped conductor

facing the first sheet-shaped conductor in such a manner as to produce capacitance between the first and second sheet-shaped conductors. In this arrangement, the loop antenna is formed with the first and second loop antennas so that a strong radio wave can be transmitted from the loop antenna. Furthermore, a large capacitance is created between the first and second sheet-shaped conductors. This make it possible to suppress the influence of the stray capacitance with a small number of components having a small volume. As a result, it is possible to produce a thin transmitting apparatus having a reduced overall size.

CLAIMS

1. A receiving apparatus in a thin form, comprising:  
a thin case in which a receiver is housed;  
a loop antenna for receiving a radio wave, said loop antenna being disposed in said case and connected to said receiver; and  
a capacitive reactance element disposed in the middle of a part between two predefined stray-capacitance-coupling points of said loop antenna so that said capacitive reactance element is inserted in a series fashion in said loop antenna, the capacitance of said capacitive reactance element being set so that resonance occurs in said part at a predetermined resonance frequency.
2. The receiving apparatus in a thin form, according to Claim 1, wherein:  
said loop antenna includes a plurality of parts which are long in distance to a wall of said case and also including a plurality of parts which are short in said distance compared to said long parts, said plurality of short parts being defined as those parts between stray-capacitance-coupling points; and  
said capacitive reactance element is disposed in the middle of each part between the stray-capacitance-coupling points so that each said capacitive reactance element is inserted in a series fashion in said loop antenna, the capacitance of each said capacitive reactance element being set so that resonance occurs at a predetermined resonance frequency in each said part between the stray-capacitance-coupling points.

3. The receiving apparatus in a thin form, according

to Claim 1 or 2, wherein said capacitive reactance element is inserted in the middle of said part between the stray-capacitance-coupling points of the loop antenna so that said capacitive reactance element is inserted in a series fashion in the loop antenna, said capacitive reactance element being disposed at the center of said part between the stray-capacitance-coupling points.

4. The receiving apparatus in a thin form, according to Claim 1 or 2, wherein: said loop antenna is formed in the shape of a polygon having vertices disposed near the wall of said case and also having vertices disposed far from the wall of said case; and said capacitive reactance element is disposed at said vertices far from the wall of said case, the capacitance of said capacitive reactance element being set so that resonance occur in the part between said vertices near the wall of said case at the predetermined frequency.

5. The receiving apparatus in a thin form, according to Claim 1 or 2, wherein said case is formed in the shape of a quadrangle; and said loop antenna is formed in a substantially circular shape.

6. The receiving apparatus in a thin form, according to Claim 1 or 2, wherein:

    said case houses a substrate therein;

    said loop antenna includes: a first loop antenna for receiving a radio wave, said first loop antenna being disposed on one surface of said substrate and connected to said receiver; and a second loop antenna for receiving the radio wave, said second loop antenna being disposed on the other surface of said

substrate and connected to said receiver; and

said loop antenna further includes: a first sheet-shaped conductor disposed in said first loop antenna; and a second sheet-shaped conductor disposed in said second loop antenna, said second sheet-shaped conductor facing said first sheet-shaped conductor in such a manner as to produce capacitance between said first and second sheet-shaped conductors.

7. A transmitting apparatus in a thin form, comprising:

a thin case in which a transmitter is housed;

a loop antenna for transmitting a radio wave, said loop antenna being disposed in said case and connected to said transmitter; and

said capacitive reactance element is disposed in the middle of each part between the stray-capacitance-coupling points so that each said capacitive reactance element is inserted in a series fashion in said loop antenna, the capacitance of each said capacitive reactance element being set so that resonance occurs at a predetermined resonance frequency in each said part between the stray-capacitance-coupling points.

8. The transmitting apparatus in a thin form, according to Claim 7, wherein:

said loop antenna includes a plurality of parts which are long in distance to a wall of said case and also including a plurality of parts which are short in said distance compared to said long parts, said plurality of short parts being defined as those parts between stray-capacitance-coupling points; and

said capacitive reactance element is disposed in the

middle of each part between the stray-capacitance-coupling points so that each said capacitive reactance element is inserted in a series fashion in said loop antenna, the capacitance of each said capacitive reactance element being set so that resonance occurs at a predetermined resonance frequency in each said part between the stray-capacitance-coupling points.

9. The transmitting apparatus in a thin form, according to Claim 7 or 8, wherein said capacitive reactance element is inserted in the middle of said part between the stray-capacitance-coupling points of the loop antenna so that said capacitive reactance element is inserted in a series fashion in the loop antenna, said capacitive reactance element being disposed at the center of said part between the stray-capacitance-coupling points.

10. The transmitting apparatus in a thin form, according to Claim 7 or 8, wherein: said loop antenna is formed in the shape of a polygon having vertices disposed near the wall of said case and also having vertices disposed far from the wall of said case; and said capacitive reactance element is disposed at said vertices far from the wall of said case, the capacitance of said capacitive reactance element being set so that resonance occur in the part between said vertices near the wall of said case at the predetermined frequency.

11. The transmitting apparatus in a thin form, according to Claim 7 or 8, wherein: said case is formed in the shape of a quadrangle; and said loop antenna is formed in a substantially circular shape.

12. The transmitting apparatus in a thin form, according to Claim 7 or 8, wherein:

    said case houses a substrate therein;

    said loop antenna includes: a first loop antenna for receiving a radio wave, said first loop antenna being disposed on one surface of said substrate and connected to said receiver; and a second loop antenna for receiving the radio wave, said second loop antenna being disposed on the other surface of said substrate and connected to said receiver; and

    said loop antenna further includes a first sheet-shaped conductor disposed in said first loop antenna; and a second sheet-shaped conductor disposed in said second loop antenna, said second sheet-shaped conductor facing said first sheet-shaped conductor in such a manner as to produce capacitance between said first and second sheet-shaped conductors.

13. Receiving or transmitting apparatus constructed and arranged to operate substantially as hereinbefore described with reference to and as illustrated in Figures 1 to 13 of the accompanying drawings.



Application No: GB 9625970.0  
Claims searched: All

Examiner: James Porter  
Date of search: 18 March 1997

**Patents Act 1977**  
**Search Report under Section 17**

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK CI (Ed.O): H1Q (QDH, QJA, QKA, QKX)

Int CI (Ed.6): H01Q 1/27, 1/52, 7/00, 23/00; H04B 1/034, 1/08, 1/38

Other: Online database: WPI

**Documents considered to be relevant:**

Category	Identity of document and relevant passage	Relevant to claims
X	GB2100063 A (TOKYO SHIBAURA) See p1 lines 23-34, p2 lines 21-31 and claims 1, 2, 6, 7 & 9	7, 12
A	EP0334297 A (SEIKO)	
X	US4004228 A (INTEGRATED ELECTRONICS) See whole document; in particular see col 4 lines 16-39	7

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.